TECHNICAL REPORT

EFFECTS OF EXERCISE-HEAT STRESS WHILE WEARING FIVE TOXIC AGENT PROTECTIVE SYSTEMS

B.S. Cadarette, L. Levine, J.E. Staab, M.A. Kolka and M.N. Sawka

The views, opinions and or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy or decision unless so designated by other official documentation.

Human subjects participated in these studies after giving their informed consent. Investigators adhered to AR 70-25 and USMRDC Regulation 70-25 on Use of Volunteers in Research.

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13. ABSTRACT *(Maximum 200 words)*

This study evaluated heat strain in four developmental toxic agent protective systems relative to the standard Toxic Agent Protective (TAP) suit during exercise-heat stress. Eight subjects (6M,2F) completed five experiments in a 38°C, 30% rh climate, wearing: (1) Self Contained Toxic Agent Protective Outfit (STEPO) with rebreather (STEPO-R); (2) STEPO with tether (STEPO-T); (3) Improved Toxicological Agent Protective (ITAP) suit with Self-Contained Breathing Apparatus (ITAP-SCBA); (4) ITAP with blower (ITAP-B); and (5) TAP. Experiments were treadmill walking at 0.89 m•sec-1, 0% grade, exercise/rest cycles of 20/10 min, for 240 min in STEPO and 120 min in ITAP. Mean metabolic rates were: 1) STEPO-R, 298±26 W; 2) STEPO-T, 299±34 W; 3) ITAP-SCBA, 275±26 W; 4) ITAP-B, 255±27 W; and 5) TAP, 222±40 W. In STEPO, subjects received whole body cooling at; STEPO-R, 200±36 W; and STEPO-T, 186±59 W. In ITAP, subjects received shirt only cooling at: ITAP-SCBA 172±34 W; and ITAP-B, 178±41 W. TAP had no cooling. Comparisons were not made between STEPO and ITAP systems. Exposure time was longer ($p<0.05$) in STEPO-R (83±22 min) and STEPO-T (106±39 min) than in TAP (46±10 min). Exposure time was longer ($p<0.05$) in ITAP-SCBA (85±20 min) and ITAP-B (87±25 min) than in TAP(46±10 min). Rate of heat storage (S) was less ($p<0.05$) in STEPO-R (37±8 W•m-2) and STEPO-T (38±12 W•m-2) than in TAP (77±15 W•m-2). S was less ($p<0.05$) in ITAP-SCBA (51±16 W•m-2) than in TAP (77±15 W•m-2). Microclimate cooling significantly reduced S in three of four systems and increased exposure time in all four systems relative to TAP.

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EXECUTIVE SUMMARY

This study evaluated whether four developmental toxic agent protective systems induced greater or less heat strain than the standard Toxic Agent Protective (TAP) suit during exercise-heat stress. Eight subjects (6M,2F) completed five experiments, all in a 38°C, 30% rh climate, while wearing: (1) Self Contained Toxic Agent Protective Outfit (STEPO) with rebreather (STEPO-R); (2) STEPO with tether (STEPO-T); (3) Improved Toxicological Agent Protective (ITAP) suit with Self-Contained Breathing Apparatus (ITAP-SCBA); (4) ITAP with blower (ITAP-B); and (5) TAP. All experiments used treadmill walking at 0.89 m•sec^{-1}, 0% grade at exercise/rest cycles of 20/10 min. This resulted in metabolic rates of 1) STEPO-R, 298±26 W; 2) STEPO-T, 299±34 W; 3) ITAP-SCBA, 275±26 W; 4) ITAP-B, 255±27 W; and 5) TAP, 222±40 W. Both STEPO systems had whole body cooling delivered; STEPO-R, 200±36 W; and STEPO-T, 186±59 W. Both ITAP systems had hooded, long sleeve shirt cooling: ITAP-SCBA 172±34 W; and ITAP-B, 178±41 W. TAP had no cooling. Subjects attempted exercise-heat stress bouts of 240 min in STEPO and TAP, and 120 minutes in ITAP. Comparisons were not made between STEPO and ITAP systems. Exposure time was longer ($p<0.05$) in STEPO-R (83±22 min) and STEPO-T (106±39 min) than in TAP (46±10 min). Exposure time was longer ($p<0.05$) in ITAP-SCBA (85±20 min) and ITAP-B (87±25 min) than in TAP(46±10 min). Rate of heat storage (S) was less ($p<0.05$) in STEPO-R (37±8 W•m^{-2}) and STEPO-T (38±12 W•m^{-2}) than in TAP (77±15 W•m^{-2}). S was less ($p<0.05$) in ITAP-SCBA (51±16 W•m^{-2}) than in TAP (77±15 W•m^{-2}). Subjects were not successful at completing hoped for exposure times. Cooling systems significantly reduced S in three of four systems relative to TAP. New generation toxic

cleanup systems with microclimate cooling can effectively reduce heat stress and increase work capabilities.

INTRODUCTION

In the management and shutting down of chemical weapons arsenals, the U.S. Army oversees the storage, maintenance, clean-up and destruction of highly toxic substances. It is essential that those workers who routinely clean-up spills or otherwise handle the toxic munitions wear protective uniform systems. In the years prior to 1988, the Toxic Agent Protective (TAP) uniform was the Army standard for use in toxic environments which pose an "immediate danger to life and health" (IDLH). The TAP consists of a coverall type, button-up suit fabricated entirely of butyl coated nylon material. The TAP is worn with butyl rubber boots; an M17 or M40 protective mask for respiratory protection; a butyl rubber hood which covers the head, neck and shoulders; and butyl rubber gloves. The TAP suit is worn over cotton sateen shirt , trousers, gloves and three pairs of socks all of which are impregnated with chlorinated paraffin. When worn under the TAP, the impregnated clothing outfit is designed to protect the wearer from small liquid droplets of vapors and blister agents. The TAP suit uses no microclimate cooling. The standard TAP suit including chemically impregnated undergarment weighs approximately 9.5 kg.

By 1987, in accordance with the Occupational Safety and Health Administration's safety limits for allowable exposure to chemical warfare agents, the Surgeon General of the Army and the Army Materiel Command (AMC) safety community (AMC Surgeon General, AMC Safety Office, AMC Field Safety Activity Office) identified the need for a new protective ensemble. The new uniform system, the Self-Contained Toxic Environment Protective Outfit (STEPO) was developed under contract for the Survivability Directorate, U.S. Army Natick Research, Development and Engineering

Center (NRDEC). The STEPO was designed for personal protection in highly toxic, unknown or oxygen deficient environments that pose an IDLH. The STEPO systems were designed to be totally encapsulating and self-contained, not relying on filtered breathing air as does the TAP suit. An interim STEPO (STEPO-I) was developed and introduced in 1988 to replace the TAP suit in IDLH environments (Levine, Cadarette, Sawka et al., 1989, Levine, Quigley, Cadarette et al., 1990, Pandolf, Levine Cadarette et al., 1989). The STEPO-I and the TAP suit thus became the protective systems currently fielded for both Explosive Ordnance Disposal (EOD) and Chemical Weapons Arsenal (Depot) personnel.

The STEPO-I was intended as a single purchase item, but did undergo some minor changes to improve fabric wear between 1988 and 1995. A new generation of STEPO has been designed to provide personal protection for up to 4 hours. The newest generation was designed to outperform the STEPO-I in terms of reduced heat stress, improved load carriage and improved flame resistance, as well as both industrial chemical and chemical warfare agent protection. These expectations were based on a change in the garment fabric, the results of fabric and manikin evaluations, improvements in the system's weight carrying distribution, and an improved microclimate cooling system (MCC). Complete descriptions of the two newest STEPO systems, the self-contained breathing (rebreather) apparatus (STEPO-R) and the tethered air-line (STEPO-T) can be found in Appendix A.

During the refinements of the STEPO system, it became apparent that there should also be a second uniform system which could be worn in place of the TAP. This uniform would be designed for a 2 hour exposure time and worn in environments where

chemical agents may be present in liquid and vapor form. It was projected that potential users of this system would be Army, Navy, Air Force and Marine EOD personnel, Army Tech Escort and Army Depot hazardous material handlers. This developmental system is called the Improved Toxicological Agent Protective (ITAP) system. The outer shell of the ITAP system is made out of the same fabrics as the STEPO system and includes the integral booties. Rather than being all encompassing with a large visor, the ITAP has a hood which fits snugly over the head, leaving the face exposed with a rubber gasket at the border of the hood. The rubber gasket interfaces with protective face masks. Standard TAP gloves and TAP over boots are worn with the ITAP system. The ITAP system has two breathing systems: either a 60 minute Self-Contained Breathing Apparatus (ITAP-SCBA) or the standard gas mask with lightweight in-line blower (ITAP-B). Cooling is provided by the Personal Ice Cooling System (PICS) .

METHODS

EQUIPMENT

The STEPO system is designed for maximal use time of 4 hours from donning to doffing in ambient temperatures up to 38°C (100°F) with no dew point limitations specified. The system includes an impermeable suit which totally encapsulates the body. The system also includes a personal vapor compression MCC with a rated cooling capacity of 375 W at a 35°C ambient temperature. The fielded MCC would include a full body cooling undergarment (head, torso, legs) which has over 300 ft of integral, small diameter cooling lines, an umbilical hose, the MCC unit, and a power supply (4 BA5590 lithium batteries). For the current study, power was supplied through

an adapter using a standard AC output. The refrigerant in the MCC is HFC 134A, while the hoses circulate a 25% propylene glycol/water solution through the undergarment. The MCC unit was floor mounted for this research study, but normally would be carried to the work site, then set on the ground while duties are completed. The weight of the cooling unit including batteries is 10 kg.

Respiratory protection in STEPO is provided in one of two ways. The users either wear a self-contained breathing apparatus (STEPO-R) with a maximum 4-hour capability, or a tethered airline to a safe air supply while workers are in the toxic environment (STEPO-T). The STEPO-R system uses a closed circuit rebreather which circulates exhaled air through a CO_2 scrubber. The scrubbed effluent is then mixed with an O_2 stream supplied from an attached compressed air bottle, passes over a frozen canister which helps reduce the air temperature and is then reintroduced to the respirator face piece. The total STEPO-R configuration including uniform, cooling garment and respiratory system, but without the MCC, weighs approximately 27 kg. Respiratory protection in STEPO-T is provided by a combination of two breathing systems: the tethered air supply and an Emergency Breathing Apparatus (EBA). The tethered air can be supplied to the system through up to 300 feet of hose, and the EBA system is a 7 kg tank carried by the user with an automatic converter switch from the tethered supply to the EBA if the tethered system should shut down. The EBA provides up to 30 minutes of safe breathing air to egress the toxic environment. The total STEPO-T configuration including uniform, cooling garment and EBA, but without the MCC, weighs approximately 22 kg.

The ITAP system is designed for maximal use time of 2 hours from donning to doffing in ambient temperatures up to 38°C (100°F) with no dew point limitations specified. The system includes an impermeable suit which encapsulates the body totally except for the face area. The ITAP system also includes a Personal Ice Based Cooling System (PICS) which pumps a cooled water/glycol mixture through the tubing system in a hooded, long sleeved shirt worn next to the skin. The cooling system provides a nominal 150 watts of cooling with the ice bottle being changed every 30 minutes in the current study. Respiratory protection is provided in one of two ways. The users either wear a self-contained breathing apparatus (ITAP-SCBA) with a maximum 60 minute use time before change, with an attached C2 canister as a back up, or a standard M40 SP or MCU/2-P mask with a lightweight in-line blower (ITAP-B) to help reduce inspiratory resistance. The ITAP-SCBA configuration weighs approximately 28 kg, the ITAP-B configuration weighs approximately 15.5 kg, and the standard TAP uniform weighs approximately 9.5 kg.

This study was performed in support of the U.S. Army Natick Research, Development and Engineering Center (NRDEC). The purpose of the study was to compare the STEPO, ITAP and TAP uniform systems for the heat strain elicited during a standardized exercise heat stress test. The study was designed to provide the following information to the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) on the STEPO and ITAP systems, respectively: (1) The safety of wearing the STEPO as an intended 4-hour maximal stay time system. This information is to be used by CHPPM for the final Health Hazard Assessment report on STEPO prior to approval for Type Classification. (2) The safety of wearing the ITAP system for a 2-hour Test and Evaluation Command (TECOM) Developmental Test/Operational Test

(DT/OT), with soldiers wearing the ITAP system and performing routine EOD and Depot tasks in the field. This information is necessary for CHPPM to approve the implementation of the DT/OT.

Because both STEPO and ITAP will be used by military and civilian personnel performing similar work, it was determined that the same heat-stress test format could be used to evaluate both systems. Therefore, eight volunteers were tested in a repeated measures study wearing each of the uniform configurations.

SUBJECTS

Eight volunteers (six men and two women) served as subjects for both the STEPO and ITAP experiments. All subjects completed medical examinations to assure there were no underlying medical problems. The subjects mean ±SD age, height, weight and % body fat of the subjects are 24±4 years, 172±10 cm, 75.1±11.4 kg and 20.9±6.1 % body fat. Demographic data on each subject is presented in Appendix B. All subjects were fully informed of the purpose, procedures and potential risks of the study and signed a statement of informed consent. Investigators adhered to guidelines established for research in humans in USARIEM M 70-68, AR 70-25 and USAMRMC 70-25 on the Use of Volunteers in Research.

EXPERIMENTAL DESIGN

Preliminary testing consisted of anthropometric measure [height, weight, estimate of % body fat by subcutaneous skinfold thickness at four sites (Durnin and Womersley, 1974)] which provided descriptive data on the subjects. The subjects were familiarized with the STEPO, ITAP and TAP systems, and metabolic rates were collected to

measure cost of exercise. The subjects then completed five days of exercise-heat acclimation before experiments began (Givoni and Goldman). After completing the exercise-heat acclimation program, the subjects completed five experiments, one in each of the five uniform configurations. All STEPO tests along with the TAP control were completed before any subject began ITAP experiments.

Procedures/Measurements

Metabolic rates were determined during the familiarization with each of the five uniform configurations. Metabolic rates were collected during both exercise and while seated in the uniform configurations so a proper work-rest scenario could be calculated using time weighted metabolic rates. It was estimated that repeated exercise-rest cycles of 20 minutes exercise, 10 minutes rest would result in a time weighted metabolic rate similar to that measured for workers performing clean-up and explosive ordnance duties at the Dugway Proving Ground (Appendix C).

Prior to the heat stress tests, the subjects were familiarized to walking on the treadmill while wearing the STEPO-R, STEPO-T, ITAP-SCBA, ITAP-B and standard TAP (with impregnated undergarment) uniform configurations. The energy cost of walking on the treadmill at 0.89 $m \cdot sec^{-1}$, 0% grade and seated rest while wearing these uniforms was collected on five of the eight subjects during familiarization in STEPO and on six of the eight subjects during familiarization in ITAP. Expired respiratory gases were collected and analyzed using a Sensormedics 2900 Metabolic Cart. Using rest/exercise cycles of 10/20 minutes for the 4-hour tests, the time weighted mean±sd energy cost of the subjects in each uniform configuration was STEPO-R 298±26 W, STEPO-T 299±34 W ITAP-SCBA 275±26 W, ITAP-B 255±27 W and TAP 222±40 W.

The metabolic rates from these work-rest cycles were similar to the metabolic rates found during simulated field tests at Dugway Proving Ground measuring the energy costs of soldiers performing 4 hours of EOD and Depot tasks while wearing STEPO (Appendix C).

During clean-up, storage and monitoring activities, the required tasks performed while dressed in STEPO, ITAP or TAP are identical, although duration can differ. Also the STEPO-R configuration and the ITAP-SCBA have nearly identical weights. Therefore, it was decided to approximate the metabolic rates from the Dugway test for the STEPO and ITAP heat strain evaluations. The mean metabolic rate measured for EOD work at Dugway was 329 W and for Depot work was 298 W. The STEPO metabolic rates in the current study were very similar to those in Dugway, and the ITAP metabolic rates in the current study were somewhat lower. However, unlike Dugway, the energy expenditure in the current study was regulated with predetermined steady state treadmill walks interspersed with fixed rest periods. At Dugway the tasks were more varied, and because the work was self-paced, metabolic rates were occasionally quite high for brief periods followed by prolonged rest breaks, while at other times the work was slow and steady. Dry bulb ambient conditions were more severe in the current study than at Dugway. However, there was no solar load in the current study as opposed to the natural sunlight experienced at Dugway.

The subjects then participated in the five day, exercise-heat acclimation program. Acclimation consisted of treadmill walking at 1.56 $m \cdot sec^{-1}$ on a 4% grade for two 50-minute exercise sessions with 10 minutes of seated rest prior to the first walk and between the two walks. Environmental conditions during heat acclimation were 40.0°C

T_{db}, 19.4°C T_{dp}, 30% rh. During acclimation, subjects wore shorts, t-shirts and athletic shoes. They were instrumented for the monitoring of heart rate (HR) and core temperature (T_{re}). Subjects were given at least 250 ml of water or a commercial glucose-electrolyte drink before entering the heat chamber each day. During exercise, subjects were encouraged to drink water to maintain hydration throughout each acclimation session. Pre- and post-exercise weights were charted each day to assure that subjects did not undergo progressive dehydration. As an added precaution, each day before being released, subjects were required to drink sufficient fruit juice or glucose-electrolyte drink to return to their pre-exercise weights. This practice was continued throughout all experiments.

After completing the exercise-heat acclimation program, the subjects completed five experiments. All tests were performed in an environmental chamber set at 38°C, 30% rh, no wind. In each STEPO and TAP experiment, the subjects attempted 240 minutes of total exposure with repeated rest/exercise cycles of 10 minutes rest and 20 minutes of treadmill walking. ITAP tests were conducted with the same rest/exercise cycles, but for a total heat exposure of 120 minutes. The treadmill was set at 0.89 m•sec^{-1}, 0% grade for all experiments. Any given experiment was terminated at the appropriate endpoint (either 240 or 120 minutes) of heat exposure, predetermined core temperature endpoint (T_{re}=39.5°C) or HR endpoint (90% age predicted maximal HR) criteria. Experiments were also terminated whenever a subject exhibited the symptoms or signs of an impending heat injury, when a subject chose volitional termination, or at the discretion of the medical monitor or investigator.

The subjects performed the experiments first in the two STEPO configurations and the TAP suit in a counterbalanced order to avoid an order effect on results. The two ITAP configurations were then tested in a counterbalanced order. On each experimental test day, the subjects received at least 500 ml of a glucose-electrolyte drink immediately after obtaining the nude weight at arrival. This was the only liquid available to them until conclusion of the day's experiment. Experiments were conducted with both morning and afternoon sessions. Subjects always reported at the same starting time, and there were approximately 44 hours between tests for recovery and rehydration.

During all tests, T_{re} was measured by a flexible thermocouple probe inserted to a depth approximately 10 cm beyond the anal sphincter. During experiments, skin temperature (T_{sk}) was measured with a four site skin thermocouple harness (chest, arm, thigh, calf). Mean weighted skin temperature (T_{sk})was calculated using the weighting system of 0.3 chest, 0.3 arm, 0.2 thigh and 0.2 calf (Ramanathan, 1964). $T_{re,}$ T_{sk} and T_{sk} were obtained by a computerized data collection system. HR was obtained from an electrocardiogram (chest electrodes, CM5 placement), displayed continuously on an oscilloscope cardiotachometer unit. Whole body sweating rate was calculated from the change in nude body weight during the entire exposure. Heat storage (S) in $W \bullet m^{-2}$ was calculated from the equation $S=[(m_b \bullet c_b)/A_D] \bullet (dT_b/dt)$, where m_b is the mean body weight (kg), during the experiment; c_b is the specific heat constant (0.965 $W \bullet h \bullet {}^{\circ}C^{-1} \bullet kg^{-1}$); A_D is the DuBois surface area (m^2); dT_b is the change in mean body temperature (°C) where $T_b=0.2 \bullet T_{sk}+0.8 \bullet T_{re}$; and dt is the exposure time (h) of the experiment.

Subjects entered the chamber and were connected for on-line collection of T_{re}, T_{sk}, and HR. Flow rate and temperature change of the coolant supplied to the cooling garments in the STEPO and ITAP configurations were also collected. The subjects sat for a 10-minute rest followed by 20 minutes walking at 0.89 $m \cdot sec^{-1}$ on a level treadmill. This pattern was repeated throughout the attempted 4-hour and 2-hour tests for STEPO and ITAP, respectively. During the ITAP experiments it was required that the ice packs to the cooling system be changed every 30 minutes. Also, in ITAP-SCBA, the SCBA tanks were changed as needed, depending on the respiratory rate of the subject.

Statistical Analysis

Data were provided on the subjects' endurance time, final core temperature (T_{ref}), final heart rate (HR_f), and heat storage (S) in each of the three uniforms for end point comparison. ANOVA were conducted for core temperature (T_{re35}), mean weighted skin temperature (T_{sk}) and heart rate (HR_{30}), at 35 minutes of exposure when all subjects were still present in all tests. ANOVA was also performed on calculated time for core temperature to reach 39°C, based on the slope of the individual core temperature responses during the first exercise bout. Wherever possible, data from flow rate and inlet/outlet coolant temperature change were used to calculate the heat removed by the MCC. This was then used to calculate the mean cooling provided within each STEPO and ITAP configuration. Data were not available on all subjects to calculate cooling. The Tukey Test was used to isolate the uniform systems which differed from each other at the $P<0.05$ level.

RESULTS

STEPO RESULTS

Mean endurance time ±SD for the three uniforms were STEPO-R, 83±22 minutes; STEPO-T, 106±39 minutes and TAP, 46±10 minutes (Figure 1). TAP endurance was significantly shorter than both STEPO configurations. Mean final core temperature ±SD for the three uniforms were STEPO-R, 37.74±0.36°C; STEPO-T, 37.76±0.40°C; TAP, 38.12±0.46°C. Mean final HR ± SD for the three uniforms were STEPO-R, 126±22 b•min^{-1}; STEPO-T, 121±21 b•min^{-1}; and TAP, 138±17 b•min^{-1}. Neither the final values for core temperature or HR could be statistically analyzed, as they occurred at different times in each volunteer. Individual data on each subject's final values is presented in Appendix D.

In the six subjects with data available, the total cooling provided by the vapor compression MCC was 200±36 W for the STEPO-R configuration and 186±59 W for the STEPO-T configuration (Figure 2). The mean heat storage for the uniforms were 37±8 W•m^{-2} for STEPO-R, 38±12 W•m^{-2} for STEPO-T, and 77±15 W•m^{-2} for TAP (Figure 3). Heat storage in TAP was significantly greater than in both the STEPO configurations.

At 35 minutes of heat exposure, the mean core temperature for the three uniforms were 37.24±0.18°C for STEPO-R, 37.28±0.20°C for STEPO-T, and 37.73±0.17°C for TAP. The 35 minute core temperature in TAP was significantly greater than both STEPO configurations. At 35 minutes of heat exposure the mean skin temperature for the three uniforms were 34.40±1.59°C for STEPO-R, 34.70±0.98°C for STEPO-T and

37.77±0.21°C for TAP. Mean skin temperature in TAP was significantly greater than in both STEPO configurations. HR was taken at 30 minutes rather than at 35 minutes as this was the last minute of the exercise bout. At 30 minutes of heat exposure, the mean HR for the three uniforms were 101±15 $b{\bullet}min^{-1}$ for STEPO-R, 112±10 $b{\bullet}min^{-1}$ for STEPO-T and 131±14 $b{\bullet}min^{-1}$ for TAP. The mean 30-minute HR in TAP was significantly greater than in both STEPO configurations.

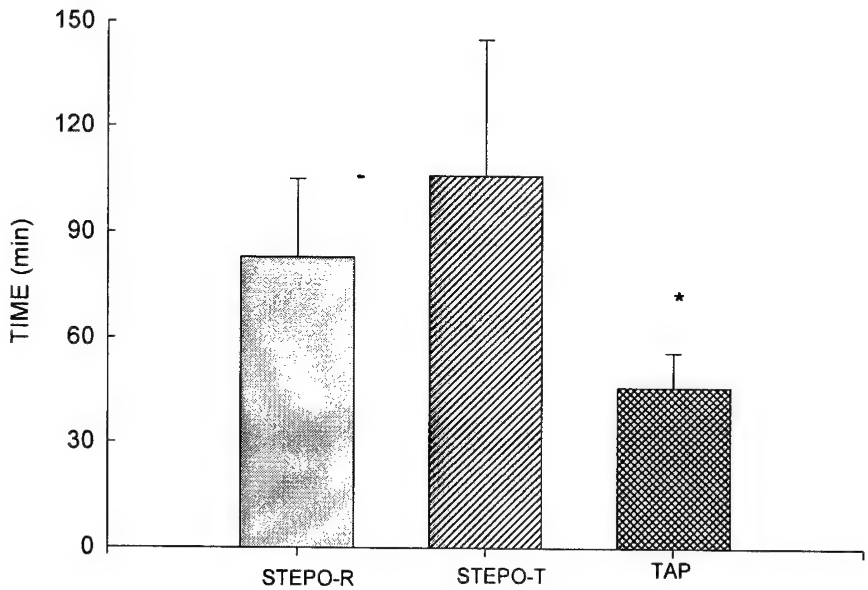

Figure 1. Mean ±SD endurance time in the STEPO and TAP uniforms during exercise at 38°C, 30% rh. * Significantly different from both STEPO configurations ($p<0.05$).

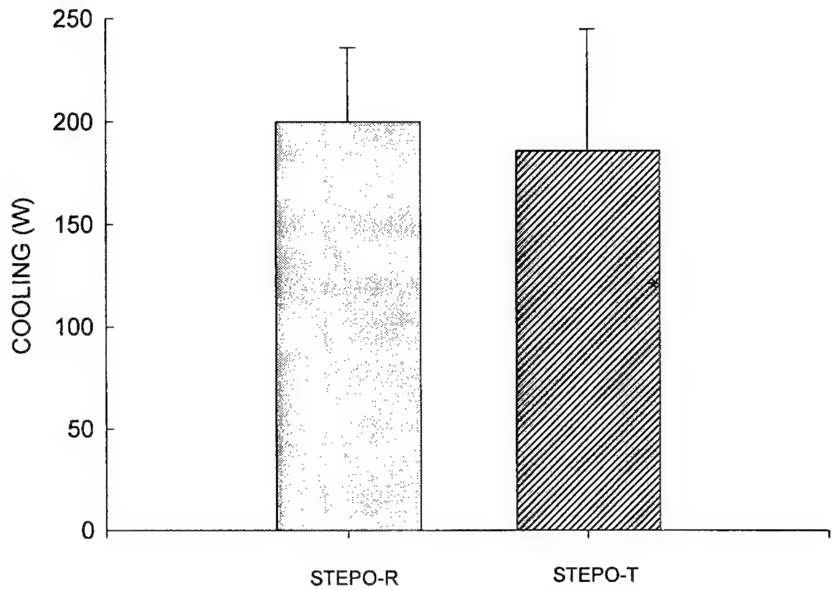

Figure 2. Mean ±SD cooling in watts provided by the vapor compression cooling system in each STEPO configuration during exercise at 38°C, 30% rh.

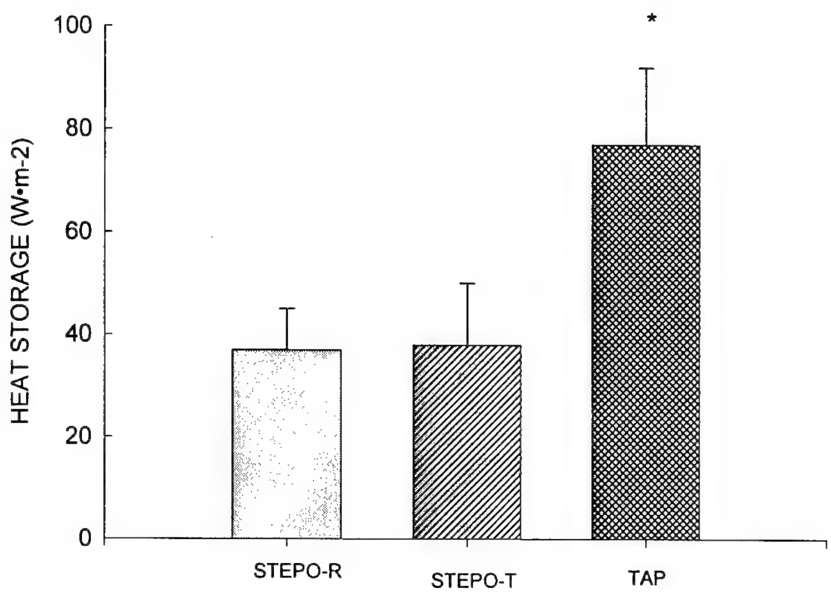

Figure 3. Mean ±SD heat storage in the STEPO and TAP uniforms during exercise at 38°C, 30% rh.
* Significantly different from both STEPO configurations ($p<0.05$).

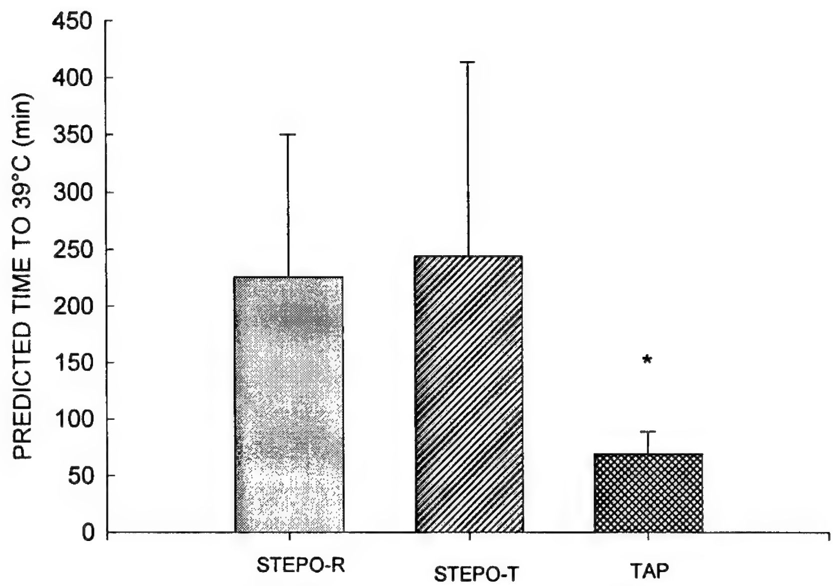

Figure 4. Mean ±SD predicted time to core temperature of 39°C in minutes in the STEPO and TAP uniforms c at 38°C, 30% rh. * Significantly different from both STEPO configurations ($p<0.05$).

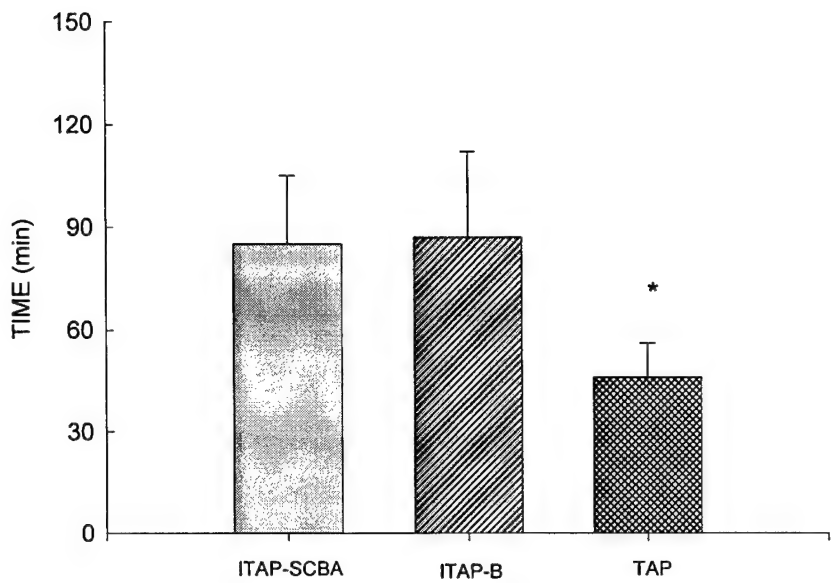

Figure 5. Mean ±SD endurance time in the ITAP and TAP uniforms during exercise at 38°C, 30% rh. * Significantly different from both ITAP configurations ($p<0.05$).

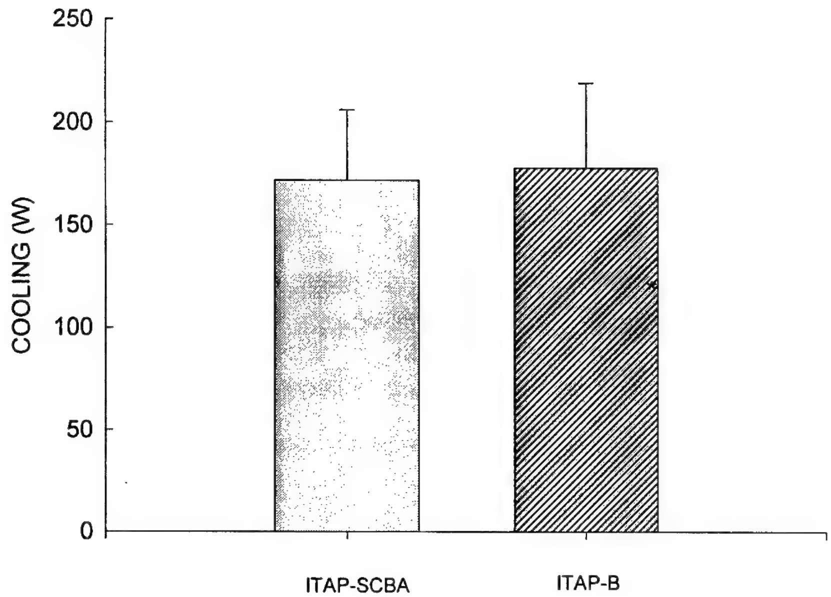

Figure 6. Mean ±SD cooling in watts provided by the personal ice cooling system in each STEPO configuration during exercise at 38°C, 30% rh.

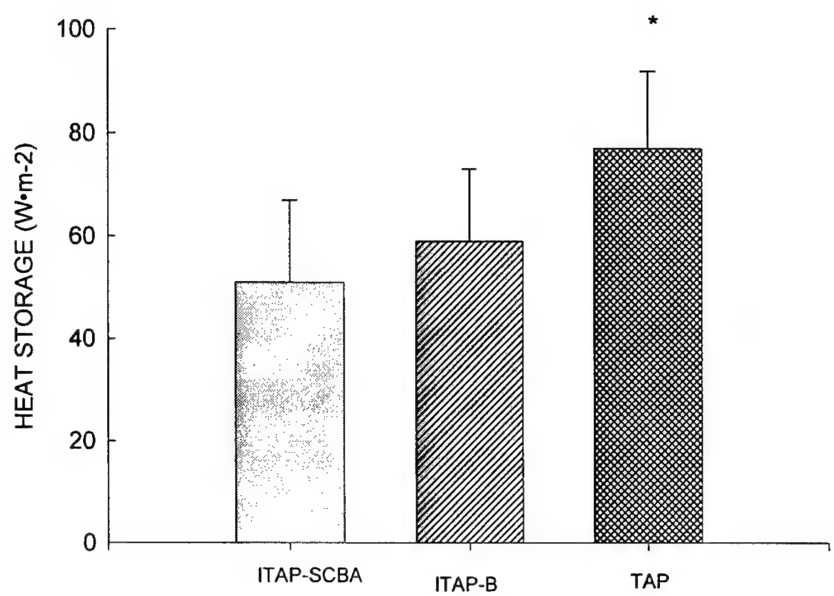

Figure 7. Mean ±SD heat storage in the ITAP and TAP uniforms during exercise at 38°C, 30% rh.
* Significantly different from the ITAP-SCBA configuration ($p<0.05$).

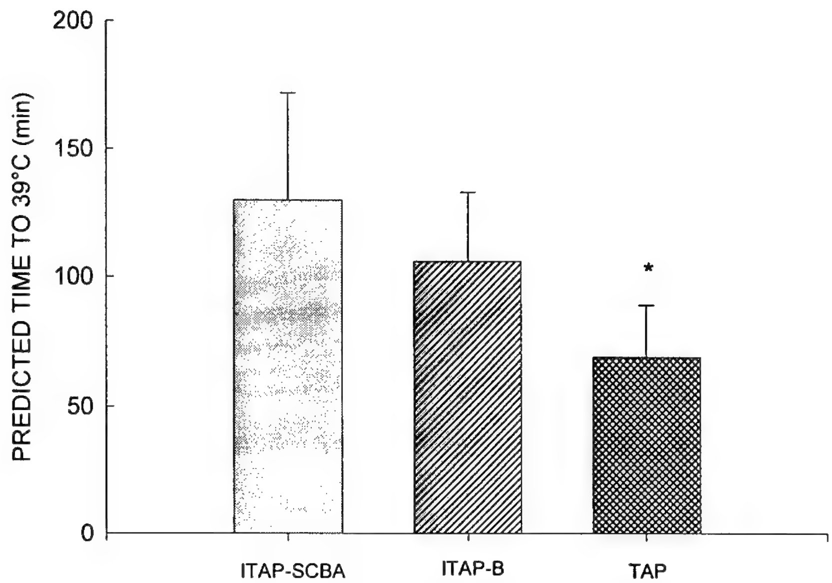

Figure 8. Mean ±SD predicted time to core temperature of 39°C in minutes in the ITAP and TAP uniforms during exercise at 38°C, 30% rh. * Significantly different from the ITAP-SCBA configuration ($p<0.05$).

The calculated times to core temperatures of 39°C based on slopes from the first exercise bout were 226±124 min for STEPO-R, 244±170 min for STEPO-T and 69±20 min for TAP (Figure 4). The calculated time for TAP was significantly less than for both STEPO configurations.

ITAP RESULTS

Mean endurance times ±SD for the three uniforms were ITAP-SCBA, 85±20 minutes; ITAP-B, 87±25 minutes and TAP, 46±10 minutes (Figure 5). TAP endurance was significantly shorter than both ITAP configurations. Mean final core temperature ±SD for the three uniforms were ITAP-SCBA, 38.04±0.30°C; ITAP-B, 38.32±0.50°C; TAP, 38.12±0.46°C. Mean final HR ± SD for the three uniforms were ITAP-SCBA, 139±19 b•min^{-1}; ITAP-B, 150±9 b•min^{-1}; and TAP, 138±17 b•min^{-1}. Neither the final core temperature or HR values could be statistically compared, as they occurred at different times in each volunteer. Individual data on each subject's final values is presented in Appendix E.

The total cooling provided to the subjects by the PICS worn with the ITAP-SCBA uniform was 172±34 W, and with the ITAP-B uniform was 178±41 W (Figure 6). The mean heat storage for the uniforms were 51 ±16 W•m^{-2} for ITAP-SCBA, 59 ±14 W•m^{-2} for ITAP-B, and 77±15 W•m^{-2} for TAP (Figure 7). Heat storage in TAP was significantly greater than in the ITAP-SCBA configuration.

At 35 minutes of heat exposure, the mean core temperature for the three uniforms were 37.37±0.19°C for ITAP-SCBA, 37.51±0.17°C for ITAP-B and 37.73±0.17°C for TAP. The 35-minute core temperature in TAP was significantly greater than both ITAP

configurations. At 35 minutes of heat exposure, the mean skin temperature for the three uniforms were 35.25±1.06°C for ITAP-SCBA, 35.45±0.31°C for ITAP-B and 37.77±0.21°C for TAP. Mean skin temperature in TAP was significantly greater than in both ITAP configurations. HR was taken at 30 minutes rather than at 35 minutes as this was the last minute of the first exercise bout. At 30 minutes of heat exposure, the mean HR for the three uniforms were 115±17 b•min^{-1} for ITAP-SCBA, 123±13 b•min^{-1} for ITAP-B and 131±14 b•min^{-1} for TAP. The mean 30-minute HR in TAP was significantly greater than in ITAP-SCBA.

Finally, the calculated times to core temperatures of 39°C based on slopes from the first exercise bout were 130±42 min for ITAP-SCBA, 106±27 min for ITAP-B and 69±20 min for TAP (Figure 8). The calculated time for TAP was significantly less than for ITAP-SCBA.

DISCUSSION

STEPO

The two STEPO configurations showed clear advantages in reducing heat strain relative to the TAP uniform in this set of experiments. All parameters measured at 35 minutes showed less heat strain in both STEPO configurations with their whole body cooling systems, than in the TAP with no auxiliary cooling. There were no significant differences between the STEPO uniform configurations.

The stay times for both the STEPO-R and STEPO-T uniform configurations were respectively 1.8 and 2.3 times that of the currently fielded TAP with impregnated

coveralls. Therefore, not only were the final core temperatures of the subjects in the two STEPO configurations more than 0.35°C lower than in the TAP uniform, but the stay times in the STEPO configurations were approximately 2:1 relative to TAP. Final HR were also 12 and 17 b•min $^{-1}$ less than in TAP in the STEPO-R and STEPO-T configurations, respectively, although the subjects in the two STEPO configurations lasted nearly twice as long in the experiments.

The stay times in both STEPO configurations as well as the TAP uniform were less than the desired 240 minutes. In part, this was a result of the naive subject population who were not used to being totally encapsulated for extended periods as are EOD and Depot personnel. It must also be noted that even with the 200 W and 186 W of cooling provided in the two STEPO configurations, the subjects still experienced approximately 40 W•m^{-2} of heat storage resulting in increased core temperature and HR (Pandolf, Allen, Gonzalez et al., 1987, Pandolf and Goldman, 1978). This level of heat storage would eventually be enough to cause anyone to cease working, and is likely to have a more rapid impact on individuals not accustomed to being encapsulated in impermeable clothing. There were also problems of comfort and fit with the uniforms, but as stated earlier, the enforced-pace, steady-state walking imposed on the test subjects was quite different from the varied, self-paced routine duties of EOD and DEPOT personnel. The primary concern of these experiments was to determine the safety and efficacy of wearing the STEPO uniforms in an uncompensable heat stress situation. Based on the findings it is our assessment that if the batteries used in the field can assure a constant flow rate and temperature through the cooling garment, the STEPO uniforms as currently configured are superior to the TAP suit in reducing heat strain and should be considered sufficient for Type Classification in this area.

ITAP

The stay times for both the ITAP-SCBA and ITAP-B uniform configurations were both 1.9 times that of the currently fielded TAP with impregnated coveralls. Therefore, while comparison of the final core temperature among the three uniforms showed them to be nearly identical, the stay time in both ITAP configurations were nearly 2:1 relative to TAP. Final HR among the three uniforms were also similar, although the subjects in the two ITAP configurations lasted nearly twice as long in the experiments.

The two ITAP configurations showed clear advantages in reducing the effects of heat strain relative to the TAP uniform in this set of experiments. The 35-minute values for core temperature and skin temperature are both greater in TAP than in the two ITAP configurations which provide the upper body cooling. The ITAP-B configuration, while lighter than the ITAP-SCBA, did result in both heat storage and 35-minute HR values which were not significantly different from the TAP uniform. This may be because the ITAP-B was blowing ambient 38°C air into the uniform and the breathing air was also at ambient temperature. The subjects in ITAP-SCBA received positive pressure breathing assist each time they began an inhalation from the SCBA tank, and because the breathing air was supplied by a pressurized tank, the air was cooled as it expanded between the tank and the subjects respiratory system.

The stay times in both ITAP configurations as well as the TAP uniform were less than the desired 120 minutes. In part, this may be a result of the naive subject population who were not accustomed to being totally encapsulated for extended periods as are EOD, Tech Escort and Depot personnel, and in part it may be related to the rate of heat storage even in the ITAP uniforms provided with upper body cooling.

Although the ITAP-SCBA provided 172 W of cooling and the ITAP-B 178 W of cooling, and these were very close to the 186 and 200 W of cooling provided in the STEPO tests using these same subjects, the PICS provided cooling only to the torso and arms, with a resultant heat storage of 51 W for ITAP-SCBA and 59 W for ITAP-B. It is likely that using torso and arms only cooling provides either insufficient surface area or not necessarily the most efficient surface area to provide cooling for the encapsulated individuals. Further research is required to determine both the optimal surface areas and optimal temperatures at which to provide microclimate cooling with liquid. The data also indicate a fairly steady state cooling response from the PICS with the ice change outs occurring every 30 minutes. If the tactical situation required a longer time between changes, the cooling rate would drop off as the ice reservoir melted.

There were problems of comfort and fit with the uniforms, especially the SCBA tank harness design, which placed stress on the neck and shoulders of all eight subjects. These are problems which can be corrected during the developmental phase of the uniform system. The primary concern of these experiments was to determine the safety of wearing the ITAP uniforms in an uncompensable heat stress situation, and based on the findings, it is our assessment that if the same procedures are followed in the field for changing ice packs, and fresh batteries are used to assure a constant flow rate through the cooling shirt, the ITAP uniforms as currently configured should be superior to the TAP suit in reducing heat strain during a DT/OT.

ALTERNATIVE USE OF PICS

Consequent to the completion of these tests and prior to receiving data on the outcome, the user community expressed interest in using the PICS as an alternative MCC for STEPO. When worn with the ITAP uniform configurations, the PICS system provided approximately 175 W of cooling by pumping a water/glycol mixture through the tubing system of a hooded, long sleeved shirt worn next to the skin. An ice bottle changed every 30 minutes was used to cool the water/glycol mixture after it had picked up ambient and body heat while passing through the shirt tubing. The cooling shirt was similar to the shirt used in the whole body cooling garment of the STEPO experiments, except with a lower density of tubing per surface area of the shirt. The STEPO tests also utilized cooling trousers over the thigh and lower leg.

It is difficult to extrapolate the effectiveness of using the PICS system with the STEPO configurations, as this has never been evaluated. However, while subjects stored heat at just under 40 $W \cdot m^{-2}$ with the vapor compression microclimate cooling and whole body cooling garment, they stored over 50 $W \cdot m^{-2}$ with the PICS system and the shirt only cooling garment. It is unlikely that this rate of heat storage would improve if the PICS system was used with STEPO using the shirt only cooling garment. STEPO is more totally encapsulating than ITAP, and in the rebreather configuration, STEPO is heavier than the heaviest ITAP configuration, potentially resulting in greater heat storage than observed with ITAP. If the user community is interested in using the PICS system with the whole body cooling garment of STEPO, further experimentation would be required first to examine questions such as (1) Is the pump sufficiently large to supply all the additional tubing with adequate flow? (2) What would be the increased power drain on the battery system? (3) How much more frequently would the ice need

to be changed? and (3) What level of cooling could be provided over the greater surface area by the ice-based system? The PICS system is not safely acceptable for use with the STEPO system without answers to at least these questions.

CONCLUSION

The new generation of toxic clean-up systems, whether a version of STEPO or ITAP, can effectively reduce heat stress and increase work capabilities, because of the MCC included in the systems. It has not yet been determined what cooling system will provide the most favorable heat removal to equipment weight ratio. All of the improvements to the STEPO and ITAP which make them a safer alternative to wearing the TAP suit also come with a significant weight and therefore metabolic burden to the toxic waste worker. While the STEPO and ITAP improve the workers safety through enhanced respiratory and clothing protection, and increase work capacity through MCC, it is important that ergonomic improvement to weight distribution be considered. Developers should also be alert to any technological breakthroughs which will lessen the metabolic burden on the toxic waste worker.

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APPENDIX A

STEPO system, ITAP system and TAP suit descriptions

The STEPO system consists of a totally encapsulating suit; two clean-air breathing systems, one self-contained and one for tethered use; a microclimate cooling system (MCC) and a communications system.

The STEPO outer shell is a one piece garment with integral booties, back pod (to enclose backpack rebreather), visor, air tight closure, exhaust valves, passthrough, support harness and glove assembly. The material is light in weight and color, is flexible and is composed of PFTE (Teflon°) and NOMEX °. The fabric has an integrated monomer film which helps decay static charge across the surface. The visor, incorporated into the head portion of the suit, provides a wide field of vision. The visor is a multi-laminate film consisting of a 10 mil fluorinated ethylene polypropylene (FEP) film which is machine laminated to a 7-10 mil hydrophilic film. The FEP is permanently welded to the suit. The hydrophilic film provides anti-fogging. The gloves (butyl viton) for the system are interchangeable, depending on the chemical hazard.

The MCC (modified EXOTEMP) has a rated cooling capacity of 375 W at an ambient temperature of 35°C. For a 4-hour mission, the liquid based cooling system is supplied 280 W of cooling at 18°C delivery temperature. The system is composed of a full body cooling garment (head, torso, legs) with at least 300 ft of integral, small diameter cooling lines, umbilical hose, MCC unit and power supply (4 BA5590 lithium batteries). Refrigerant in the MCC unit is HFC 134A, and in the hoses is 25% propylene glycol in distilled or de-ionized water. The unit is carried to the work site and

set on the ground during operations. The weight of the cooling unit with batteries is 10 kg.

The self-contained breathing apparatus (R, Biomarine BioPak 240) has a 4-hour capability and was redesigned for the STEPO program. The improvements from the standard BioPak 240 for the STEPO program are reduced size (front to back profile reduced ~6 inches) and weight (reduced by 6.2 lbs). The weight of the STEPO-R system, carried as a backpack under the STEPO shell is 15 kg. The system is composed of a full face piece, respirable gas container, gas pressure gauge, service life indicator, hand-operated valves, O_2 relief system, adjustable harness system, optical inserts, O_2 source, positive pressure breathing bag, a relief system to vent excess breathing O_2 outside the suit and an O_2 leak senor. The closed-circuit rebreather circulates exhaled air through a CO_2 scrubber. The effluent is then mixed with an O_2 stream supplied from a compressed air bottle, and is then reintroduced into the respirator face piece where it is inhaled. Exhalation resistance is 2 inches of water and inhalation resistance is 4 inches of water. The mask contains a speaking diaphragm and lens insert to reduce fogging. The STEPO-R air is cooled by use of a frozen gel tube to lower the temperature of the rebreathed air.

The tethered air line (STEPO-T) with an emergency breathing apparatus (EBA) is a combination of two breathing systems. The EBA is redesigned from an existing NIOSH approved system. The STEPO-T has a supplied air system operated at an inlet pressure of 110-125 psig with a supply hose of up to 300 feet in length. The 30 minute EBA is an aluminum tank, fully wrapped with fiberglass and weighs 7 kg when charged to 4500 psig. A first stage regulator located at the cylinder neck reduces the cylinder pressure to 135-155 psig. A pressure demand valve located on the face piece provides

air to the user and maintains a positive pressure to the face piece. The system is equipped with a visual pressure gauge and an audible low pressure alarm which sounds at 25% of cylinder operating pressure.

APPENDIX B

Demographics of the eight test subjects

SUBJECT	AGE (YRS)	HEIGHT (CM)	WEIGHT (KG)	BODY FAT (%)	GENDER
1	21	159	66.9	29.6	F
2	21	185	78.9	12.9	M
3	28	171	77.4	20.8	M
4	19	159	62.5	27.8	F
5	21	171	68.2	12.5	M
6	27	172	83.6	20.5	M
7	23	184	96.8	21.3	M
8	31	171	66.8	21.6	M
X	24	172	75.1	20.9	
SD	4	10	11.4	6.1	

APPENDIX C

MCMR-UE-EMT (70) 4 August 1995

MEMORANDUM THRU

Chief, Thermal Physiology and Medicine Division,

U.S. Army Research Institute of Environmental Medicine

Director, Environmental Physiology and Medicine Directorate,

U.S. Army Research Institute of Environmental Medicine

FOR Commander, U.S. Army Natick Research, Development and Engineering Center, ATTN: SSCNC-IPS (Mr. Matt Whipple, Survivability Directorate)

SUBJECT: Self Contained Toxic Environment Protective Outfit: Metabolic Rate Determination

1. The Self Contained Toxic Environment Protective Outfit (STEPO) is designed for personal protection in highly toxic or oxygen-deficient environments that pose an "immediate danger to life and health." This garment was developed by the U.S. Army

Natick Research, Development and Engineering Center, Natick, MA, to replace the previously used Toxic Agent Protective (TAP) suit and is to be fielded for Explosive Ordnance Disposal (EOD) and Chemical Weapons Arsenal (DEPOT) personnel. The STEPO consists of a totally encapsulating protective outer shell, a self-contained breathing system carried as a backpack rebreather (STEPO-R) or tethered to an outside clean air supply (STEPO-T) and an MCC. This study was designed to determine the metabolic rate of EOD and DEPOT personnel during activities in a field setting during operational testing (OT) at Dugway Proving Ground (DPG) in Utah. The purpose for determination of metabolic rates during OT was to allow a better approximation of exercise intensity for a subsequent environmental chamber study which will evaluate the heat strain induced by STEPO.

2. Following medical clearance, eight male soldiers volunteered to serve as test subjects for this investigation. After being informed of the purpose, procedures and risks of the study, the soldiers signed an informed consent statement. All subjects had been participating in the STEPO OT at DPG for ~ 2-6 months. Subjects were military personnel, 20 to 32 years of age, who worked within EOD and DEPOT. The physical characteristics of the subjects (mean ± SD) were: age; 26.3 ± 3.5 yrs, weight; 82.4 ± 17.8 kg (181.6 ± 39.3 lbs) and height; 178.1 ± 4.6 cm (70.1 ± 1.8 inches) (Subappendix C-1).

3. The subjects were briefed by the USARIEM staff on the requirements and procedures of the protocol for metabolic rate determination during EOD and DEPOT scenarios. On the following day, metabolic rate was calculated by measuring oxygen

uptake ($\dot{V}O_2$) on a minute by minute basis from a calibrated oxygen measurement system (Oxylog, P.K. Morgan Instruments, Inc., Andover, MA). Four subjects were tested during each test session. Two subjects performed a 4-hour EOD scenario wearing STEPO-R, while the other two subjects performed a 4-hour DEPOT scenario wearing STEPO-T. The subjects performed one scenario (EOD or DEPOT) on the first day and the other scenario the following day. Two subjects were unable to interchange suits due to sizing and therefore performed the same scenario on both days (Subjects # 4 and # 8). Some modifications to STEPO were required to allow inspired and expired air to be analyzed. The mask worn with STEPO was arranged so the inspired ambient air was drawn through a turbine to allow for the measurement of inspired air volume, while expired air was delivered to the oxygen measurement system. Heart rate and skin temperatures were monitored via telemetry (WRAIR system) by DPG medical staff during all test sessions for safety purposes. (Those data are not reported here.)

4. Subappendix C-2 lists the tasks for the EOD and DEPOT test scenarios. For the purpose of reporting metabolic rate data, the scenarios were broken down into 4 primary activities for the EOD scenario and 6 primary activities for the DEPOT scenario. All the activities performed during the scenarios are included within the primary activities list. Activities such as driving the forklift and double bagging munitions were included within the primary activities because they represented only a small portion of total work time. The subjects were required to take a 15-minute rest period for each hour of work performed. The subjects also took short periodic rest breaks at their own discretion throughout the work session. The EOD and DEPOT scenarios purposely allowed for individual variation in activities and intensities. For example, one subject

may have chosen to dig rapidly for a short duration with long rest breaks as opposed to another subject who may have chosen to dig more slowly and take shorter rest breaks. Likewise, one subject may have spent more time digging than their partner. Consequently, metabolic rates measured at different times for the same activities and/or subjects will not be the same.

5. The primary activities for the EOD scenario were Walking, Standing, Digging, and Sealing. The Walking task included walking to and from the suspect site and around the test site. The Standing tasks included standing while a partner performed a task, planning strategy and light activities such as observing over exposed munitions and sampling for leaks with M18A detection kits. The Digging tasks included using hand tools to excavate munitions for inspection and performing remote fuse removal operation in accordance with typical EOD procedures. Sealing the fuse cavity required the subject to either kneel or stand over the munitions and place plaster-of-paris cloth around the munition to prevent leakage. Metabolic rates for these activities are reported in liters of oxygen uptake per minute ($\dot{V}O_2$ $l \bullet min^{-1}$) and in Watts ($W = \dot{V}O_2 * 347$). Group means ($\dot{V}O_2$ and W) for these activities, the average of all EOD procedures and the percentage of time spent on each task are presented in Subappendix C-3. Metabolic rates for each subject performing these specific tasks are reported in Subappendix C-4.

6. The primary activities for the DEPOT scenario were Walking, Standing, Sampling of Munitions, Moving Munitions, Bolting of Single Round Containers (SRC) and Banding the Munitions Crate. The Walking task included walking to and from the suspect site

and walking around the test site. The Standing tasks included standing while a partner performed a task, planning strategy and light activities such as stabilizing the SRC while a partner bolted or unbolted the "end cap." Sampling of Munitions task included standing or sitting by munitions, opening sample ports and sampling with M18A detection kit. The Moving Munitions task included stacking and unstacking the pallet of munitions to obtain the leaking munitions. Bolting of SRC task involved standing while using a ratchet to bolt or un-bolt the "end cap" on the SRC. The Crate Banding task included strapping the pallet of munition with metal bands. Group means ($\dot{V}O_2$ and W) for these activities, the average of all DEPOT procedures and the percentage of time spent on each task are presented in Subappendix C-5. Metabolic rates for each subject performing these specific tasks are reported in Subappendix C-6. On the second day of testing, only 3 subjects performed the EOD scenario due to a malfunction with an oxygen measurement system

7. The average metabolic rates for the EOD and DEPOT scenarios were 329 W (range; 263 to 417 W) and 298 W (range; 206 to 368 W), respectively. The EOD scenario data indicated that subjects worked at > 400 W for ~11 minutes, 250-350 W for ~34 minutes and rested at < 200 W for 15 minutes out of each hour. The DEPOT scenario data indicated that subjects worked at > 350 W for ~18 minutes, 250-300 W for ~7 minutes, < 250 W for ~20 minutes and rested at < 200 W for 15 minutes of each hour. These metabolic rates are somewhat lower than those previously estimated and than those used for previous environmental chamber studies to evaluate heat stress. In the latest environmental chamber tests to determine the heat stress of STEPO, the subjects walked on a treadmill for 30-40 minutes at a metabolic rate of 400 W and

rested 20 minutes per hour. The subjects were unable to complete the 4-hour test; however, none of the subjects experienced marked heat strain. Subjects working at lower metabolic rates (determined from this investigation) should be able to exercise for a longer duration and will thus give a more representative indication of the heat strain. An important consideration when attempting to simulate these metabolic rates during environmental chamber tests is that the work during the EOD and DEPOT scenarios was intermittent in nature with tasks seldom continuing for longer than 2 minutes. Therefore, using an overall average metabolic rate as a continuous work rate may not be representative of the actual work scenario due to its intermittent nature.

8. Point of contact for this action is the undersigned (DSN 256-5900; Comm: 508-233-5900.

Encls

LESLIE LEVINE
Research Physiologist

SUBAPPENDIX A-1

SUBJECT CHARACTERISTICS			
Subject #	**Age (yrs)**	**Weight (kg)**	**Height (cm)**
1	20	70	175
2	32	104	183
3	26	87	174
4	28	104	185
5	28	97	180
6	27	67	178
7	25	66	175
8	24	64	173
Group means ± SD	26.3 ± 3.5	82.4 ± 17.8	178.1 ± 4.6

SUBAPPENDIX A-2

DEPOT SCENARIO

The objective of the following scenario was to closely simulate a chemical munitions explosive in an M55 rocket storage structure. Operators wore the STEPO-T configuration. The scenario consisted of personnel taking necessary actions to render safe clean up and containerization of munitions involved in the accident. It was assumed a total of 2 munitions were damaged and out of configuration. One pallet of rockets was used for these procedures. Operators performed a sequence of events as follows:

1. Don the STEPO-T ensemble with minimum assistance.

2. An oxygen measurement system is placed on the exterior of the backpack and connections are made from the mask to the measurement system by USARIEM staff.

Note: Data collection starts when monitors are connected to the mask.

3. Walk to the accident site.

4. Perform sampling on pallet of munitions using M18A detection kit.

Note: Results will be positive for two of the rockets on the bottom of the pallet.

Subappendix A-2, cont.

5. Disassemble munitions pallets.

6. Restack rockets to get to the leaking rockets.

7. Unbolt two SRC end caps.

8. Place the leaking rockets in each SRC.

9. Replace the end caps and re-bolt.

10. Take a rest break.

11. Unbolt the two SRC “end caps”.

12. Remove the rockets from each SRC.

13. Replace the rockets on the pallet.

14. Band the pallet of rockets.

15. Move pallet out of the building with forklift.

16. Repeat the above procedure (steps 4-14) several times throughout the 4 hour scenario.

Subappendix A-2, cont.

EOD SCENARIO

The objective of the following scenario was to closely simulate a chemical munitions recovery operation. Operators wore the STEPO-R configuration. The scenario consisted of operators taking the necessary actions to recover, render safe and containerize a chemical projectile which was discovered partially buried in an area of moderately rough terrain. Operators performed a sequence of events as follows:

1. Don the STEPO-R ensemble with minimum assistance.

2. An oxygen measurement system is placed on the exterior of the backpack and connections are made from the mask to the measurement system by USARIEM staff.

Note: Data collection starts when monitors are connected to the mask.

3. Walk approximately 200 feet to the suspect site.

4. Perform gross level sampling of exposed munitions with M18A detection kit.

Note: Results will be vapor positive; no visible liquid is present.

5. Use hand tools to excavate the munitions for inspection.

Note: Inspection shows that the munitions are fused, and EOD recommendation is for onsite removal of the fuse assembly.

6. Perform remote fuse removal operation IAW typical EOD procedures.

Subappendix A-2, cont.

Note: As the fuse assembly is removed, chemical agent will begin to flow out of the burster assemble.

7. Upright the munitions to prevent further leakage.

8. Seal the fuse cavity with plaster-of-paris wrapping and allow to harden approximately 10 minutes.

9. Decontaminate the munitions and fuse, and surrounding area allowing a 5-minute contact time.

10. Double bag the munitions and fuse, then decontaminate the outer bag allowing a 5-minute contact time.

11. Perform gross level sampling of the munitions, fuse and waste materials using the M18A chemical agent detector kit.

Note: All results will be negative.

12. Walk to other suspect sites.

13. Perform the above procedure (steps 4-12) on other munitions sites.

SUBAPPENDIX C-3

EOD SCENARIOS (Group means, n= 7)			
Activity	**$\dot{V}O_2 \pm$ SD ($l \cdot min^{-1}$)**	**Watts**	**% Total Time ± SD**
Walking	0.98 ± .30	340	27 ± 7 %
Digging	1.17 ± .24	406	31 ± 11 %
Sealing	0.87 ± .28	302	17 ± 8 %
Standing	0.78 ± .12	269	25 ± 8 %
Average of Activities	0.95 ± .24	329	100 %

SUBAPPENDIX C-4

EOD SCENARIO Activity: Walking		
Subject #	**$\dot{V}O_2 \pm SD$ ($l \cdot min^{-1}$)**	**Watts**
1	1.27 ± .32	441
3	0.81 ± .34	283
4	0.98 ± .27	341
4	0.86 ± .16	299
5	1.13 ± .39	392
6	0.90 ± .39	316
7	1.00 ± .22	327
Group mean	0.98 ± .30	340

Subappendix C-4, cont.

EOD SCENARIO Activity: Digging		
Subject #	**$\dot{V}O_2 \pm SD$ ($l \cdot min^{-1}$)**	**Watts**
1	1.42 ± .39	493
3	1.18 ± .15	411
4	1.34 ± .28	465
4	0.82 ± .20	283
5	1.38 ± .27	478
6	0.88 ± .20	307
7	1.16 ± .23	402
Group mean	1.17 ± .24	406

Subappendix C-4, cont.

EOD SCENARIO Activity: Sealing		
Subject #	**$\dot{V}O_2 \pm SD$ ($l \cdot min^{-1}$)**	**Watts**
1	1.07 ± .20	371
3	0.62 ±,.13	214
4	0.91 ± .34	316
4	0.69 ± .20	240
5	1.39 ± .19	482
6	0.61 ± .05	213
7	0.81 ± .12	280
Group mean	0.87 ± .87	302

Subappendix C-4, cont.

EOD SCENARIO Activity: Standing		
Subject #	**$\dot{V}O_2 \pm SD$ ($l \cdot min^{-1}$)**	**Watts**
1	0.76 ± .29	263
3	0.82 ± .24	286
4	0.63 ± .20	227
4	0.80 ± .23	277
5	0.81 ± .45	281
6	0.62 ± .02	215
7	0.97 ± .20	337
Group mean	0.78 ± .12	269

SUBAPPENDIX C-5

DEPOT SCENARIOS (Group means, n= 8)			
Activity	**$\dot{V}O_2 \pm$ SD ($l \bullet min^{-1}$)**	**Watts**	**% Total Time ± SD**
Walking	1.03 ± .23	357	13 ± 8 %
Standing	0.61 ± .19	211	16 ± 7 %
Sampling	0.67 ± .16	230	11 ± 7 %
Moving Munitions	1.12 ± .26	390	22 ± 10 %
Bolting SRC	0.78 ± .19	272	16 ± 8 %
Banding Munitions	0.95 ± .15	328	22 ± 7 %
Average of Activities	0.86 ± .19	298	100 %

SUBAPPENDIX C-6

DEPOT SCENARIO Activity: Walking		
Subject #	**$\dot{V}O_2 \pm SD$ ($l \cdot min^{-1}$)**	**Watts**
1	1.37 ± .45	476
2	0.94 ± .42	327
3	0.92 ± .41	318
5	1.39 ± .50	485
6	0.90 ± .27	313
7	0.86 ± .18	300
8	0.83 ± .23	286
8	1.03 ± .23	358
Group mean	1.03 ± .23	358

Subappendix C-6, cont.

DEPOT SCENARIO Activity: Standing		
Subject #	**$\dot{V}O_2 \pm SD$ ($l \bullet min^{-1}$)**	**Watts**
1	0.60 ± .15	207
2	0.67 ± .22	233
3	0.76 ± .31	265
5	0.52 ± .06	180
6	0.39 ± .12	134
7	0.78 ± .23	272
8	0.54 ± .19	188
8	0.61 ± .20	211
Group mean	0.61 ± .19	211

Subappendix C-6, cont.

DEPOT SCENARIO Activity: Sampling		
Subject #	**$\dot{V}O_2 \pm SD$ (l • min^{-1})**	**Watts**
1	0.90 ± .24	311
2	0.71 ± .14	248
3	0.70 ± .10	242
5	0.79 ± .21	275
6	0.34 ± .14	118
7	0.61 ± .09	213
8	0.57 ± .10	199
8	0.69 ± .12	240
Group mean	0.67 ± .16	231

Subappendix C-6, cont.

DEPOT SCENARIO Activity: Moving Munitions		
Subject #	**$\dot{V}O_2 \pm SD$ ($l \cdot min^{-1}$)**	**Watts**
1	1.55 ± .37	537
2	1.00 ± .33	346
3	1.09 ± .34	378
5	1.46 ± .35	505
6	0.78 ± .01	272
7	1.17 ± .20	406
8	0.96 ± .23	333
8	0.99 ± .21	344
Group mean	1.12 ± .26	390

Subappendix C-6, cont.

DEPOT SCENARIO Activity: Bolting SRC		
Subject #	**$\dot{V}O_2 \pm SD$ (l • min^{-1})**	**Watts**
1	1.00 ± .24	345
2	0.82 ± .22	284
3	0.69 ± .17	240
5	1.08 ± .11	375
6	0.48 ± .21	165
7	0.76 ± .11	262
8	0.81 ± .21	280
8	0.65 ± .18	226
Group mean	0.78 ± .19	272

Subappendix C-6, cont.

DEPOT SCENARIO Activity: Banding Munitions		
Subject #	**$\dot{V}O_2 \pm$ SD ($l \cdot min^{-1}$)**	**Watts**
1	1.11 ± .32	386
2	1.01 ± .16	349
3	0.88 ± .29	306
5	1.12 ± .34	389
6	0.68 ± .18	236
7	1.05 ± .14	365
8	0.87 ± .20	300
8	0.84 ± .14	393
Group mean	0.95 ± .15	328

APPENDIX D

Individual subject data for stay times, core temperatures and heart rates in the STEPO configurations and TAP uniform.

STAY TIMES (MIN)

SUBJECT	STEPO-R	STEPO-T	TAP
1	83	106	45
2	112	181	61
3	57	91	33
4	74	76	35
5	61	91	44
6	110	105	45
7	84	79	45
8	91	151	61
X	84	106	46
SD	20	39	10

Appendix D, cont.

FINAL CORE TEMPERATURE (°C)

SUBJECT	STEPO-R	STEPO-T	TAP
1	37.61	37.55	37.85
2	38.14	38.38	39.17
3	37.51	37.54	37.88
4	37.53	37.63	37.77
5	37.45	37.30	38.14
6	37.59	38.36	38.04
7	38.47	37.49	38.20
8	37.62	37.81	38.50
X	37.74	37.76	38.12
SD	0.36	0.40	0.46

Appendix D, cont.

FINAL HEART RATE (B•MIN^{-1})

SUBJECT	STEPO-R	STEPO-T	TAP
1	115	86	147
2	113	139	134 (REST)
3	130	112	120 (REST)
4	114	112	111 (REST)
5	142	119	160
6	131	155	135
7	168	136	148
8	96	111	151
X	126	121	138
SD	22	21	17

SUBJECTS #2, #3, AND #4 REMOVED THEMSELVES FROM TESTING IN THE TAP UNIFORM DURING SEATED REST WHICH CAUSED LOWER FINAL HEART RATES. THE FINAL EXERCISE HEART RATES FOR EACH JUST BEFORE THEY FINISHED TESTING WERE 154, 133 AND 148 B•MIN^{-1}, RESPECTIVELY. USING THESE HEART RATES WOULD HAVE RESULTED IN MEAN ± SD HEART RATES IN TAP OF 147±9 B•MIN^{-1}.

APPENDIX E

Individual subject data for stay times, core temperatures and heart rates in the ITAP configurations and TAP.

STAY TIMES (MIN)

SUBJECT	ITAP-SCBA	ITAP-B	TAP
1	56	75	45
2	75	120	61
3	90	90	33
4	84	42	35
5	65	90	44
6	113	83	45
7	90	78	45
8	108	120	61
X	85	87	46
SD	20	25	10

Appendix E, cont.

FINAL CORE TEMPERATURE (°C)

SUBJECT	ITAP-SCBA	ITAP-B	TAP
1	37.59	37.98	37.85
2	38.33	39.13	39.17
3	37.69	38.50	37.88
4	38.22	37.70	37.77
5	37.77	38.07	38.14
6	38.24	38.32	38.04
7	38.32	37.93	38.20
8	38.16	38.91	38.50
X	38.04	38.32	38.12
SD	0.30	0.50	0.46

Appendix E, cont.

FINAL HEART RATE ($B{\bullet}MIN^{-1}$)

SUBJECT	ITAP-SCBA	ITAP-B	TAP
1	130	139	147
2	135	149	134 (REST)
3	116	164	120 (REST)
4	155	138	111 (REST)
5	123	159	160
6	152	143	135
7	171	149	148
8	127	155	151
X	139	150	138
SD	19	9	17

SUBJECTS #2, #3, AND #4 REMOVED THEMSELVES FROM TESTING IN THE TAP UNIFORM DURING SEATED REST WHICH CAUSED LOWER FINAL HEART RATES. THE FINAL EXERCISE HEART RATES FOR EACH JUST BEFORE THEY FINISHED TESTING WERE 154, 133 AND 148 $B{\bullet}MIN^{-1}$, RESPECTIVELY. USING THESE HEART RATES WOULD HAVE RESULTED IN MEAN ± SD HEART RATES IN TAP OF $147{\pm}9$ $B{\bullet}MIN^{-1}$.

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